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Maintaining Photovoltaic Systems

Tips From Users in Land Management Agencies

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Introduction

Photovoltaic systems can work effectively for a variety of load applications. They are ideally suited to locations far from powerlines (Figure 1). They are also well suited to locations where the natural serenity would be destroyed by the noise of a diesel- or gas-powered generator.

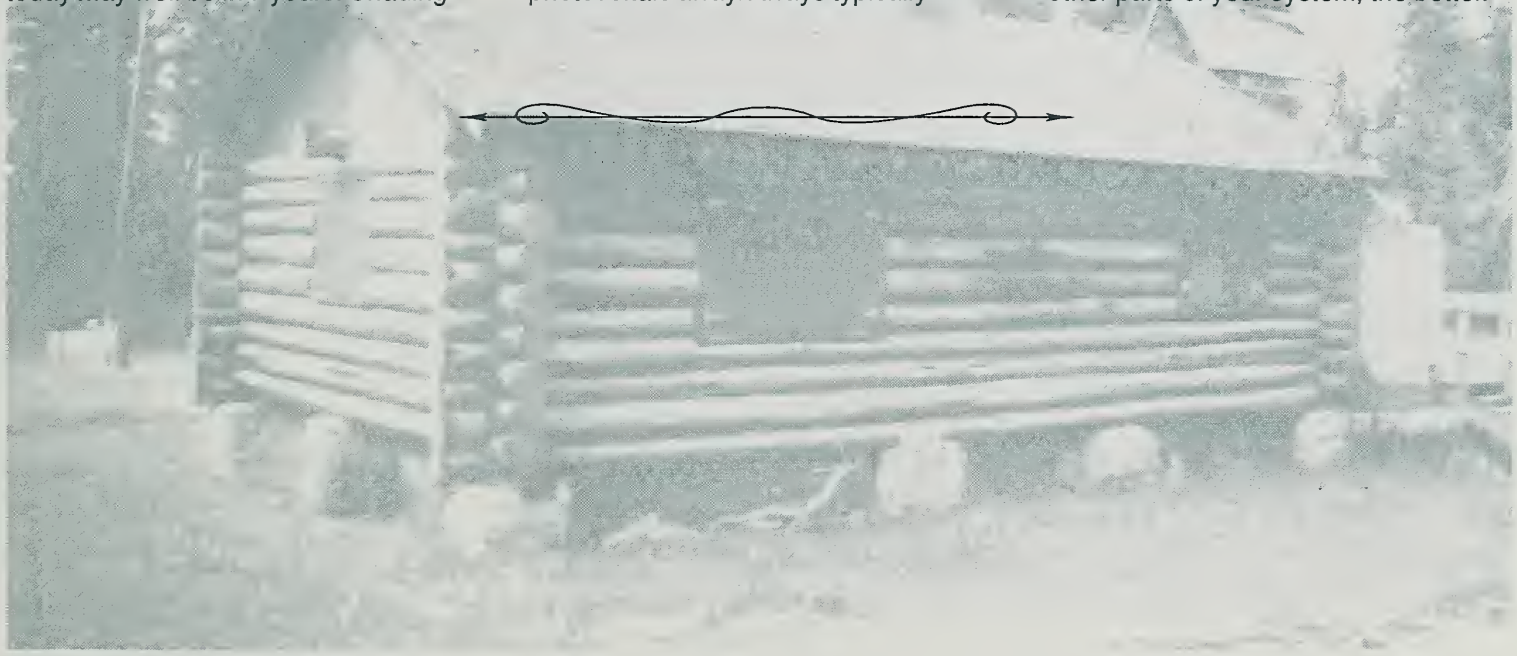
Robi Robichaud has been in the field examining photovoltaic systems from Albuquerque to Missoula, talking to people who have installed, maintained, or used these systems. He has asked them what has worked well, what has not worked well, and what they might do differently. This report is a collection of tips and advice from people living and working with these systems. It may be advisable to use a solar horizon device such as the Solar Pathfinder to assess the relative importance of shading on site selection. The Solar Pathfinder (Solar Pathfinder, Iron City, TN (931) 724-6528) shows where the sun shines in relation to the site objects for all the months of the year, so you can determine the effect of the shade from each object on total sunlight gathered.

Figure 1—Photovoltaics are ideally suited when power is needed far from powerlines. This panel powers an emergency phone system along the road to Mt. Evans on the Roosevelt National Forest in Colorado. The Colorado Department of Transportation shared the costs.

Siting Considerations

Photovoltaic systems may be in use for a decade or longer. Are there trees or mountains to the east, west, or south that will shade the array during the day? Consider how tall trees will grow over the next 5, 10, or even 20 years. A system that is not shaded at 1 p.m. today may well be in 7 years. Shading will have a negative effect on your system, even if the shading is during the early morning or late afternoon. This is especially true if the shading increases every year.

Consider the proximity of the other parts of the system and the load to the photovoltaic array. Arrays typically generate low voltage DC current that undergoes some voltage drop (with power loss) when transmitted long distances. Low voltage DC systems require heavier gauge wire than AC systems. Heavier gauge wire is needed to avoid voltage drops on DC systems. In general, the closer the array is to the other parts of your system, the better.



Vandalism

Vandalism is a consideration when siting your PV system. At campgrounds, reports of vandalism seem much less frequent when the campground has a host. Systems on the ground have typically been located in a fenced-off area, but they are often highly visible (Figure 2). Suggestions have been made to plant shrubs or vines to screen the fence (but not tall shrubs that will shade the array), reducing visibility, and perhaps vandalism.

Roof-mounted systems have several possibilities. For small systems on flat roofs, the array can be mounted near the middle of the roof with the components in watertight electrical boxes to reduce visibility and access to most components of your system.

For pitched roof systems, the relatively new “PV shingle” may be an answer to vandalism. These flexible panels are made of amorphous silicon and look like your average asphalt shingle (a variety of colors and shades are available). They withstand hail, snow, and wind better than traditional roof-mounted PV structures…and they require considerably more work to remove. The University of Denver, in conjunction with the National Renewable Energy Laboratory and others, recently installed a “roof-integrated” system at the Mt. Evans Observatory—the world's highest observatory (Figure 3). Which may make this system the world's highest PV system! Solar tiles are another option for a roof-integrated solar system. The tiles use crystalline cells instead of amorphous cells, producing nearly twice as much power as the shingles.

Lexan covers can protect typical PV panels in metal frames from damage by hail or rocks tossed by vandals. But Lexan can greatly reduce solar insolation on the panels, especially when the sun is not perpendicular to the Lexan cover. A better way to provide protection is to select solar panels that have tempered glass coverings.

Figure 2—Fencing screens but doesn't totally obscure solar panel installations such as this trailer-mounted array on the Roosevelt National Forest in Colorado.

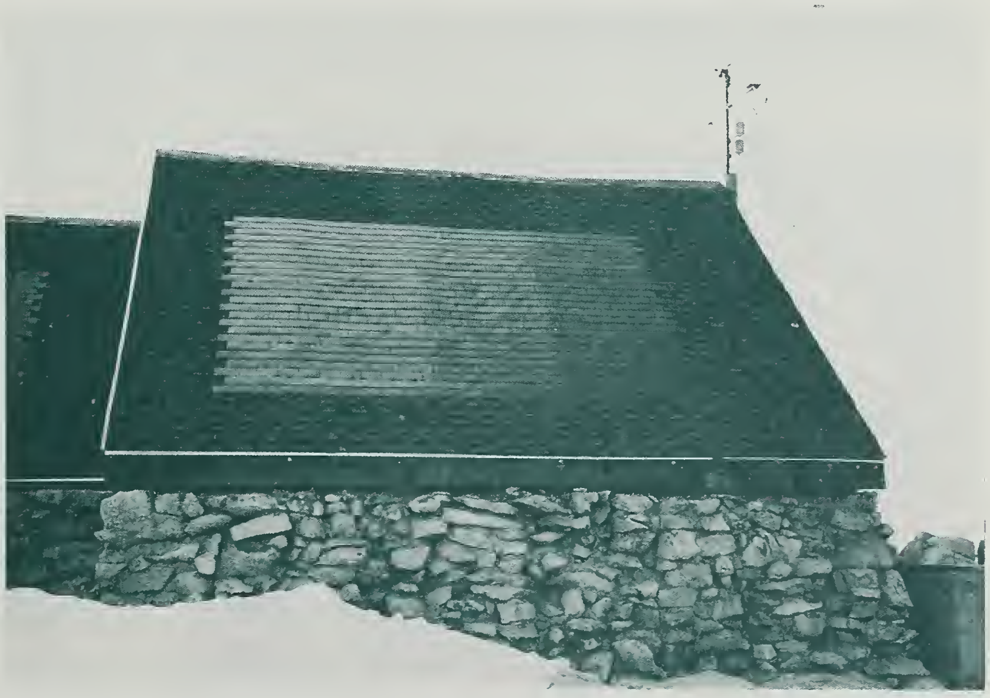


Figure 3—Photovoltaic shingles produce electricity on the roof of the Mt. Evans Observatory on the Roosevelt National Forest in Colorado. The system uses 48 shingles, each 7 feet long.

"Quick Fixes" for the Desperate

When panels are cracked, Charlie Maes of the Cibola National Forest's Sandia Ranger District uses spray polyurethane to help keep moisture out of PV materials and out of the conducting wires built into the panel. Spray polyurethane can help prolong the life of your panel. Remember, cracked glass covers on PV panels do not affect the workings of the PV cell. A cracked PV panel will still conduct electricity and often perform just as well as before it was cracked, as long as the crack does not create any significant shading of the panel.

Matching Your Load With Your PV System

After you have determined that PV represents the best way to meet your load, you need to size your system to effectively meet your daily load. It is probably best to bring in an expert to help design your system, but you want to address the following questions to be sure you get the system you need.

- Does your load need to be met all day every day? Do you need to have an electrical storage system (batteries) for extended periods when the sun does not shine? For instance, if your load consists of a water pump that pumps water to a large storage tank, will you still have enough water if the sun does not shine for 4 days? If so, then maybe you won't need a battery system to store power. Store water instead.

- If you do need batteries, how many "days of autonomy" do you need? If the sun did not shine for an extended period, how many days (days of autonomy) would you need for your battery system to carry you through?

- Can your load be met with DC electricity (the type PV panels typically produce)? If so, your system won't need an inverter. Inverters are often an expensive component of PV systems. An inverter changes DC electricity (constant, one-direction current) to AC electricity (the current changes direction 60 times per second, well, technically 120 times per second, because it changes direction twice in each cycle). AC electricity is what you use at home for your TV, stereo, and computer.

- Small, simple systems will operate best (highest efficiency, lowest cost) if they use only DC electricity. However, certain loads (such as power for home appliances in a campground host's RV) may require AC electricity, necessitating an inverter and batteries.

When sizing your PV system, consider the highest load season. Often the highest load season will be during summer (campgrounds for instance), which is usually good for solar systems. Use attached charts to determine the average number of sun-hours per day you can expect at your location during your highest load season. If your load is year-round, consider all seasons and hours of sun per day.

Use PV sizing software or a worksheet to determine the full extent of your load. You can download Windows or Macintosh sizing software from the Center for Renewable Energy and Sustainable Technology's web site *http://solstice.crest.org/cgi-bin/ssregister.pl* Determine if you need batteries for storage, a generator as a backup, DC or AC power, or both. Size your batteries according to your daily load and the number of days of autonomy you need. Size your PV system to meet your daily load with energy left over to charge your batteries.

Direct DC Systems

If you have a direct DC system (such as a water pump that only operates when the sun is shining), the motor can typically run at less than full sun, but it will run slower (Figure 4). DC motors often run at high voltages. For instance, the 10A SolarJack water runs at 90V. If the weather is partly cloudy, your array might be producing less than its normal current at a lower voltage. The result? Your pump runs slower than it "normally" runs. So, if the pump would meet your load running full bore for 5 hours a day, it might not pump enough water on a day when it is running at less than full speed.

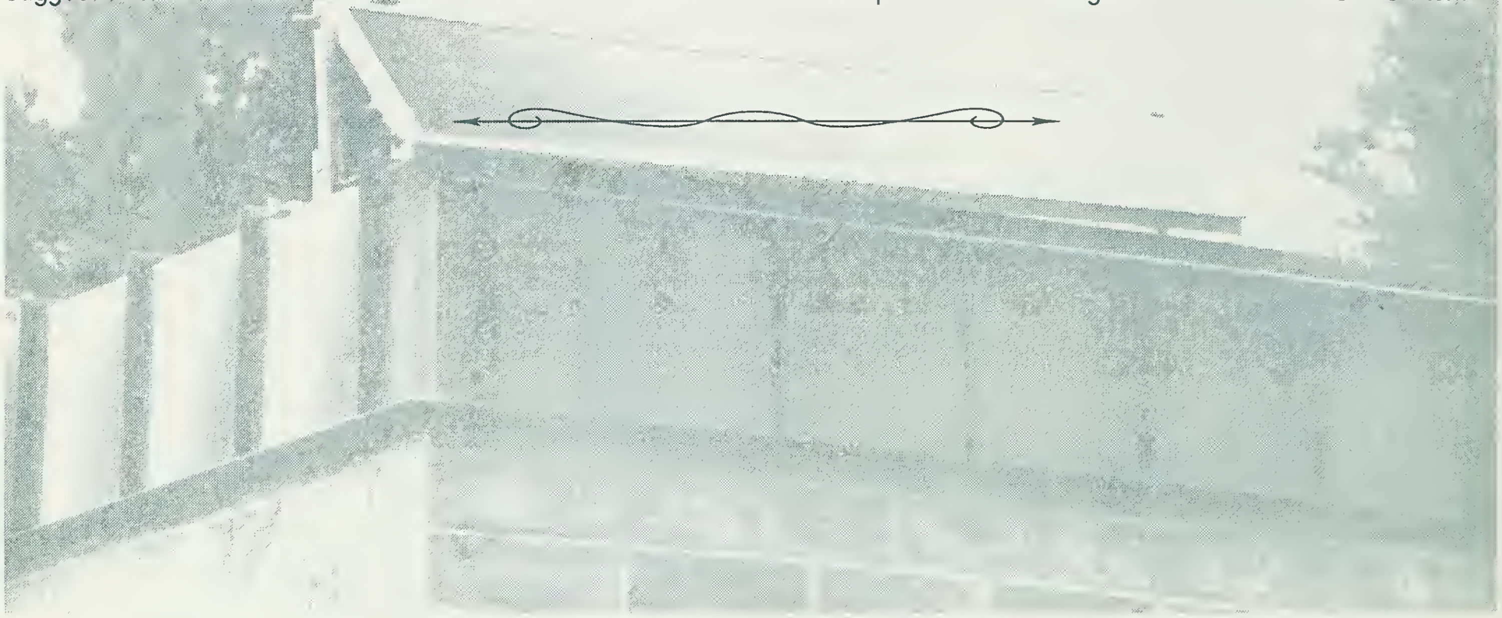
Figure 4—A photovoltaic-powered water pump installation at Wade Lake Campground on the Beaverhead National Forest in Montana.

To compensate, you might add one or two panels to your array to help keep the voltage up to the motor's specifications. Several direct DC systems at sites I visited had added more panels recently or were going to add more panels in the near future to ensure that the pumping load would be met.

AC Systems and Mixed AC/DC Systems

Your load will determine whether you should go with an AC or mixed AC/DC system. Consult your local PV dealer if you need AC power. You will need to add an inverter into your system. There

were few insightful comments from the field in this area (since many systems were DC only), other than the suggestion to use a reliable inverter. Everyone who had Trace Engineering's inverters spoke highly of them. In selecting an inverter, give careful consideration to whether or not a backup generator may be needed in certain seasons or for certain loads. If so, select an inverter that is also a battery charger with a built-in transfer switch.



Batteries

If you need to meet your load even when the sun is not shining, batteries or a backup generator will be crucial for your system. Assuming you will be using batteries as your backup power, here are some ideas you will need to consider.

Battery Storage Ideas

During the Season—Storing batteries while they're used in your system might not be as simple as it sounds. One or two batteries can be easily mounted on a roof or on a pole. When battery systems begin to include four or eight batteries, their weight requires them to be stored close to or in the ground.

Batteries can be stored inside the walk-in vault of composting or evaporative toilet systems. They should be enclosed in a ventilated box, well above the floor to avoid the danger of flooding.

- Battery boxes stored in the ground have problems with flooding, rodents (very serious issue with hantavirus), and are dangerous for even routine battery maintenance (Figures 5 and 6). To check specific gravity or electrolyte levels you must hunch over a battery pack with your eyes and head right where hydrogen gas would escape and explode if ignited, where sulfuric acid might splash... and it's just plain not good for your back to hunch over routinely to check your system.

Figure 5–Storing batteries in the ground isn't recommended...

Figure 6–...but a well-constructed box above ground can provide excellent results.

Animals can wreak havoc with an underground battery box by eating wires, shorting out your system while shortening their lives. Yes, they can do it above ground, but they don't seem to do it as often. I have come across dead mice and marmots in these boxes (and plenty of live critters that got my attention). If you have to store your battery in the ground, consider pouring a concrete box. It will be more expensive, but will probably be a lot less hassle over the long run.

Battery Box Insulation—Your battery box should be insulated to minimize temperature swings. Large temperature swings can affect a battery's performance and shorten its life. Lead acid batteries perform ideally at 77° F. At higher temperatures, batteries perform better, but they have a shorter life. At lower temperatures, batteries have a lower storage capacity. Remember, *an ounce of insulation now is worth a pound of batteries later!*

Insulation will help. But do not depend on insulation alone to keep the batteries from freezing. You may have to add more battery capacity to keep them charge levels higher to prevent freezing. Discharged batteries contain mostly water and freeze at much higher temperatures than charged batteries that have a stronger acid solution.

A good controller (such as the Trace C-40) can be wired with a temperature sensor in your battery bank. The main purpose of the charge controller is to prevent them from overcharging, which also may keep the batteries from overheating. The controller can adjust the charging voltage to maintain the temperature below 80° F or so. Such a system can be a worthwhile investment for maximizing the return from your batteries.

Off-Season Battery Storage—If your PV system won't be in use during the off-season, battery storage is often a critical issue. At the end of the season, bring your batteries in to be fully charged. Do not let the batteries freeze or fully discharge over the winter.

Battery Configuration and Maintenance

Use batteries designed for PV systems. Trojan (L-16) and DEKA (solar battery) are two of the "workhorses" in the PV industry. Batteries come in various voltage and amp-hour sizes. Using 6V batteries gives solid performance and maximum flexibility in system design. Two 6V batteries wired in series gives you the equivalent of a 12V battery.

When wiring batteries in series, you add the voltages of each battery to find the system voltage (6V + 6V + 6V + 6V = 24V system). The system amperage remains the same as in each battery. When you wire batteries in parallel, you add the amperages of the batteries to find system amperage (3A + 3A + 3A + 3A = 12A). The system voltage remains the same as in each battery.

Failure to properly maintain batteries may shorten battery life, lead to system failures, and cost money.

One of the simplest ways to reduce battery maintenance solutions is to use "gel cell" or "valve-regulated" batteries. These are deep-cycle batteries that are "sealed." You don't have to worry as much about these batteries giving off highly explosive hydrogen gas as they reach full charge, about checking their electrolyte levels, or about measuring the specific gravity of the electrolytes. These batteries can even be stored on their side. However, they must still have adequate ventilation. They have a vent to release small amounts of hydrogen gas that are formed as they reach full charge. More importantly, the charge rate on these batteries must be controlled to lower voltage to prevent gassing. Gassing in a gel cell can ruin the battery by injecting hydrogen into the gel and severely reducing the battery capacity. Keep the charge rate on gel cells at or below 14.1 volts. By contrast, wet lead-acid batteries are regularly charged up to 14.8 volts, and are equalized at 15 volts. Gel cells generally should not be equalized.

Purchase gel-cell batteries if you can. If you can't get the gel-cell batteries, purchase heavy-duty, deep-cycle, lead-acid batteries. If you use lead-acid batteries, adequate ventilation becomes even more important. They will "gas" as they reach a state of full charge. Great care should be taken when opening the battery box. Never smoke or allow any flames or sparks near your battery system.

If you get deep-cycle, lead-acid batteries, commit yourself to monthly battery inspections to ensure long battery life with full capacity. Otherwise, you may find yourself wishing you had gotten the valve-regulated, gel-cell batteries. When inspecting the batteries, check their electrolyte levels. If you need to add water, be sure to use distilled water.

One way to reduce maintenance of the deep-cycle, lead-acid batteries is to install "Hydro-caps." These caps take most of the hydrogen and oxygen that is released during gassing and return it to the battery cell. You will not have to refill the electrolyte as frequently. People in the field have suggested they can go 2 to 3 months between battery checks when using Hydro-caps.

Battery Matching and Equalizing

If you find a battery that does not get up to full charge repeatedly, it may need to be replaced. Full charge varies according to battery make, but it is about 7.1V for a 6V battery or about 14.4 for a 12V battery. If the full-charge voltage of your new battery varies from your old ones by more than about 0.2V, you will reduce overall battery system life and capacity. Try to match batteries in each system as much as possible.

Batteries should be periodically topped off or fully charged–known as "equalizing." Equalizing your batteries can help prevent sulphation on the battery plates–important for maintaining full storage capacity in your batteries. The final stages of equalizing involves trickle charging your batteries. A good controller (Trace C-40) can do this automatically for you, making it well worth the investment. If your controller doesn't do this automatically and you don't do it periodically, you will shorten the life of your battery bank. Gel cells generally should not be equalized. See the list of sources for additional information to learn more about gel cells and equalization.

PV Mounting

Tilt Angle for Array

When determining PV tilt angle:

- If the PV system is used only in the summer: subtract 10 to 15° from the latitude to get the proper tilt angle. The tilt is closer to horizontal because of high sun angles in the summer (Figure 7).

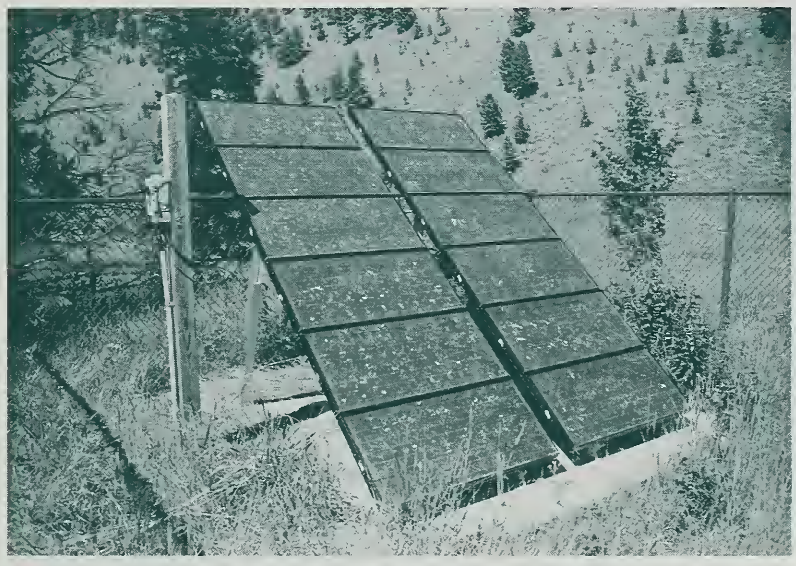


Figure 7—Tilt angle is important for solar panels. This panel is tilted about 37°, probably too steep for its location in southwestern Montana.

- If the PV system is used only in the winter: add 10 to 15° to the latitude to get the proper tilt angle, especially if snow reflection is to be considered. The tilt is closer to vertical because of low sun angles in winter. Where snow is a factor, be sure to angle the panels steeply enough (almost 90°) to make sure the snow will slide off the panels, even if this is steeper than ideal.

- If the PV system is used year-round: consider adjusting the panel seasonally. If the panel cannot be adjusted seasonally: consider your peak load season, average sun-hours per day, sun angles during the peak load season, and tilt the panel accordingly.

To Mount Vertically or Horizontally, That Is the Question

The PV panels will perform equally well whether they are vertically or horizontally oriented, so what's the big deal? When the panels are mounted horizontally, snow, leaves, pollen, or other debris can collect over the frame's horizontal metal seam and get stuck there. As "stuff" accumulates, it can easily cover more and more of the surface area of your panel (Figure 8). The same can happen to a vertically oriented panel, but the collecting edge is much shorter. Even with a lot of accumulation, a much smaller region of the vertically oriented panel will be covered.

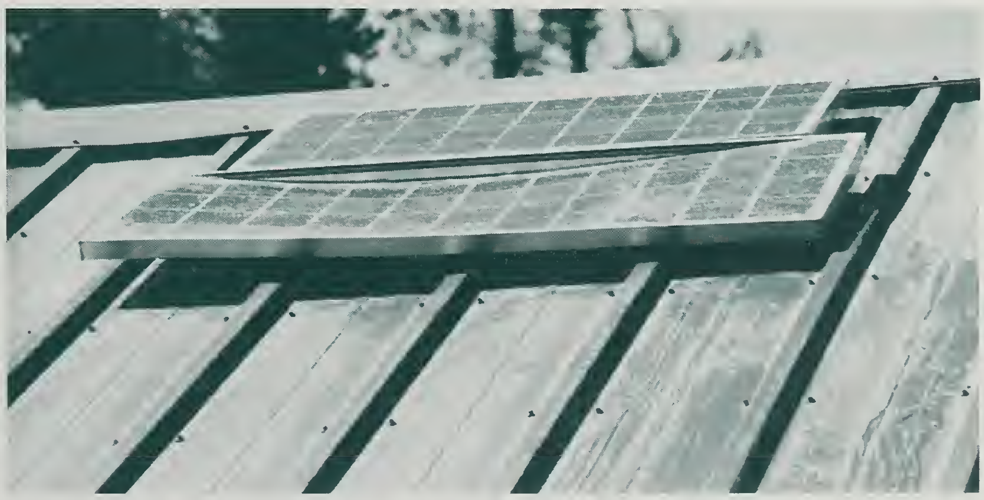


Figure 8—Snow crushed the bottom panel. Vertical mounting would probably have been better than horizontal mounting for this installation. Voltage increased 14% and current increased 7% when these panels were cleaned.

PV panels mounted vertically shed snow and other debris more easily. This mounting is definitely recommended. In some cases, horizontally mounted PV's have warped from snow loading, cracking the PV and separating it from the frame, which bowed out.

PV Trailer Systems

Everything you need can often be included in these portable, trailer-mounted systems. They have several advantages:

- They are portable and can be easily removed during the off-season, reducing the potential for damage due to extreme weather or vandalism (Figure 9).

- They can easily accommodate changing needs for PV power.

- They make yearly maintenance easier since the system is brought in for storage during the off-season.

If the trailer is to be parked somewhere for a long period of time the wheels should be removed.

Figure 9—Photovoltaic systems can be mounted on trailers for portability or to allow safe indoor storage during winter.

PV Maintenance

PV panels require little in the way of maintenance. However, if pollen, dirt, dust, leaves, and other debris collects on the surface of your panel, it should be removed by wiping, brushing, or spraying the panel with water. Dirty panels can reduce your system's power output.

DC Wiring and Fuses

DC wiring is a little different than AC. Because the current flows continuously, it is more difficult to stop the flow of power and extinguish the arc by switch or fuse blowing. Also, DC systems experience more voltage drop (loss of efficiency, loss of power) in longer wire runs. Consequently, DC wire sizes are larger, due to low voltage, for given current-carrying capacity. It has been suggested to go even one size larger in wire gauge than the National Electric Code for your system as this will further reduce your voltage drops.

DC fuses differ from AC fuses. DC fuses should be used in DC systems if at all possible. AC fuses and switches can rely on the intermittent flow of AC power to help stop the flow of electricity. Your local PV dealer should be able to help you find some DC fuses.

Be sure to follow National Electric Code color convention when wiring. Labeling your wires is also a good idea— it really simplifies things, especially when someone other than the installer must do maintenance or troubleshooting. If only one color of wire is available, be sure to use colored tape to mark the wires correctly. Special attention must be given to the DC color code because DC negative is black in automobile electrical systems, while all negatives by National Electrical Code are white or green. Do not assume that if the two DC wires are black and white that the black is negative and the white is positive . According to convention in AC power, white is negative and black is "hot," so a DC appliance or DC light with black and white wires could be wired either way.

Make secure wire connections by either using a "crimper" or the "solder and plastic shrink" method. Both are effective. Make sure solder connections are physically solid before adding solder so solder isn't the only thing holding the connection together.

Control Boxes

To make maintenance easier, keep spare fuses, circuit breakers, and connector screws in the panel box or control box. That way, if one of those parts needs to be replaced during an inspection you can replace it right away, minimizing the system's downtime and eliminating the need for a return trip.

Include maintenance forms in the control box. That way you or anyone else can quickly assess maintenance that has been done in the past, as well as tasks might need to be done now.

Controllers

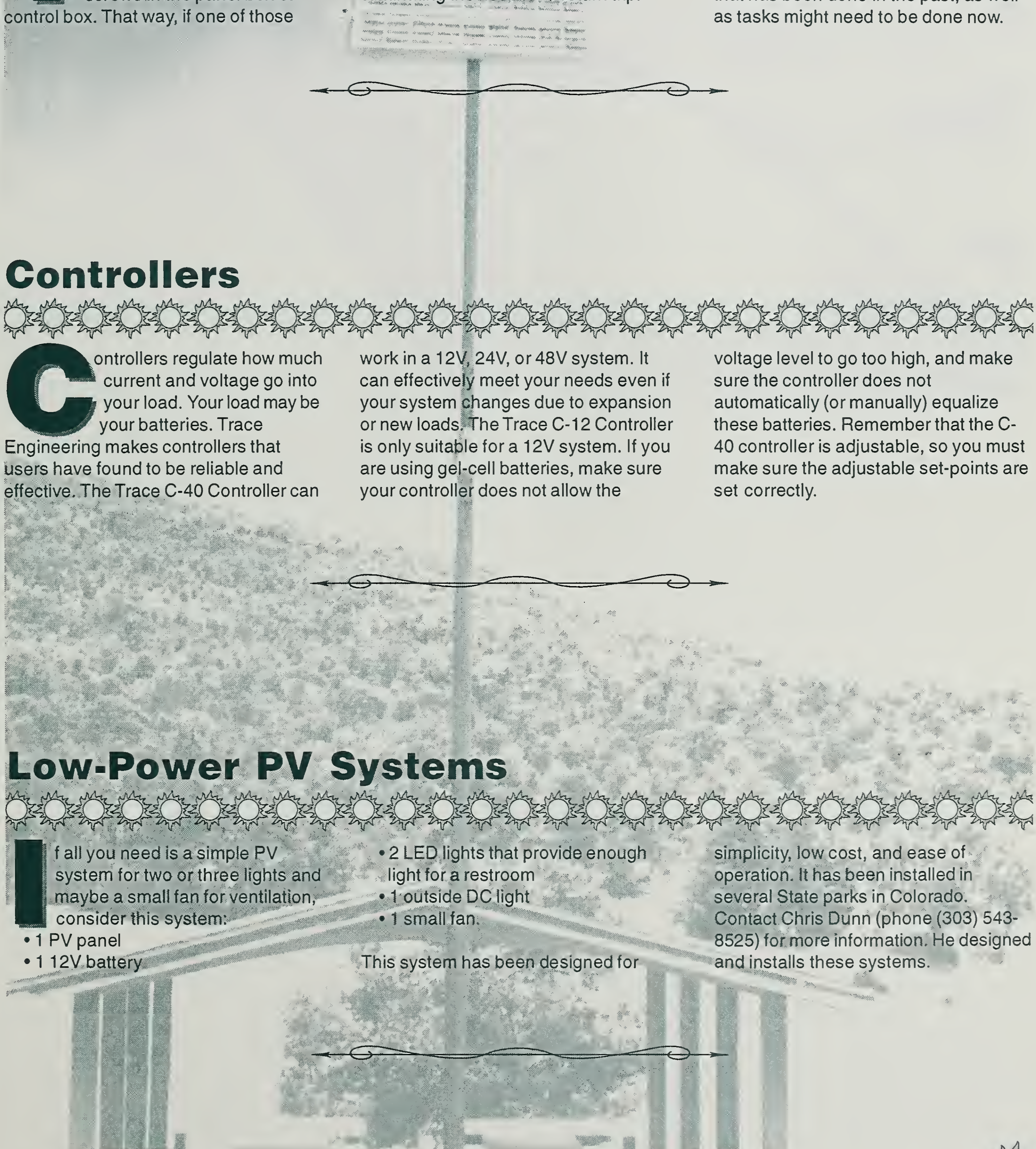
Controllers regulate how much current and voltage go into your load. Your load may be your batteries. Trace Engineering makes controllers that users have found to be reliable and effective. The Trace C-40 Controller can work in a 12V, 24V, or 48V system. It can effectively meet your needs even if your system changes due to expansion or new loads. The Trace C-12 Controller is only suitable for a 12V system. If you are using gel-cell batteries, make sure your controller does not allow the voltage level to go too high, and make sure the controller does not automatically (or manually) equalize these batteries. Remember that the C-40 controller is adjustable, so you must make sure the adjustable set-points are set correctly.

Low-Power PV Systems

If all you need is a simple PV system for two or three lights and maybe a small fan for ventilation, consider this system:

- 1 PV panel
- 1 12V battery
- 2 LED lights that provide enough light for a restroom
- 1 outside DC light
- 1 small fan.

This system has been designed for simplicity, low cost, and ease of operation. It has been installed in several State parks in Colorado. Contact Chris Dunn (phone (303) 543-8525) for more information. He designed and installs these systems.



Sources of Information About PV Systems

- Your local PV dealer

- Sandia National Laboratories
  Maintenance and Operation of Stand-Alone Photovoltaics Systems is a very thorough, yet readable, step-by-step guide. It includes information about battery equalization and other useful topics. And it is free.
  Internet: http://www.sandia.gov/pv
  Phone: (505) 844-3698

- Photovoltaic Systems Assistance Center
  Sandia National Laboratories
  Albuquerque, NM 87185-5800
  Phone: (505) 844-3698

- *The Solar Electric Independent Home Book* by Paul Jeffey Fowler
  Fowler Solar Electric, Inc.
  226 Huntington Rd.
  Worthington, MA 01098
  ISBN 1–879523–01–9

- Center for Renewable Energy and Sustainable Technology
  Internet: http://solstice.crest.org

- National Renewable Energy Laboratory
  Internet: http://www.nrel.gov

- Gel cells
  Internet: http://www.alt-energy.com/catalog/batteryinfo.html

Appendix A—Wire Loss Tables

12 Volt 2% Wire Loss Table

AMPS	Wattage	14ga	12ga	10ga	8ga	6ga	4ga	2ga	1/0	2/0	3/0
		Distance in Feet									
1	12	45	70	115	180	290	456	720	-	-	-
2	24	22	35	57	90	145	228	360	580	720	912
4	48	10	17	27	45	72	114	180	290	360	456
6	72	7	12	17	30	47	75	120	193	243	305
8	96	5	8	14	22	35	57	90	145	180	228
10	120	4	7	11	18	28	45	72	115	145	183
15	180	3	4	7	12	19	30	48	76	96	122
20	240	-	3	5	9	14	22	36	57	72	91
25	300	-	-	4	7	11	18	29	46	58	73
30	360	-	-	3	6	9	15	24	38	48	61
40	480	-	-	-	4	7	11	18	29	36	45
50	600	-	-	-	-	5	9	14	23	29	36

24 Volt 2% Wire Loss Table

AMPS	Wattage	14ga	12ga	10ga	8ga	6ga	4ga	2ga	1/0	2/0	3/0
		Distance in Feet									
1	24	90	140	230	360	580	912	-	-	-	-
2	48	45	70	115	180	290	456	720	-	-	-
4	96	20	35	55	90	145	228	360	580	720	912
6	144	15	24	35	60	95	150	240	386	486	610
8	192	11	17	29	45	71	114	180	290	360	456
10	240	9	14	23	36	57	91	145	230	290	366
15	360	6	9	14	24	38	60	96	153	192	244
20	480	-	7	11	18	29	45	72	115	145	183
25	600	-	-	9	14	23	36	58	92	116	146
30	720	-	-	7	12	19	30	48	77	97	122
40	960	-	-	-	9	14	23	36	58	72	91
50	1200	-	-	-	-	11	18	29	46	58	73

120 Volt 2% Wire Loss Table

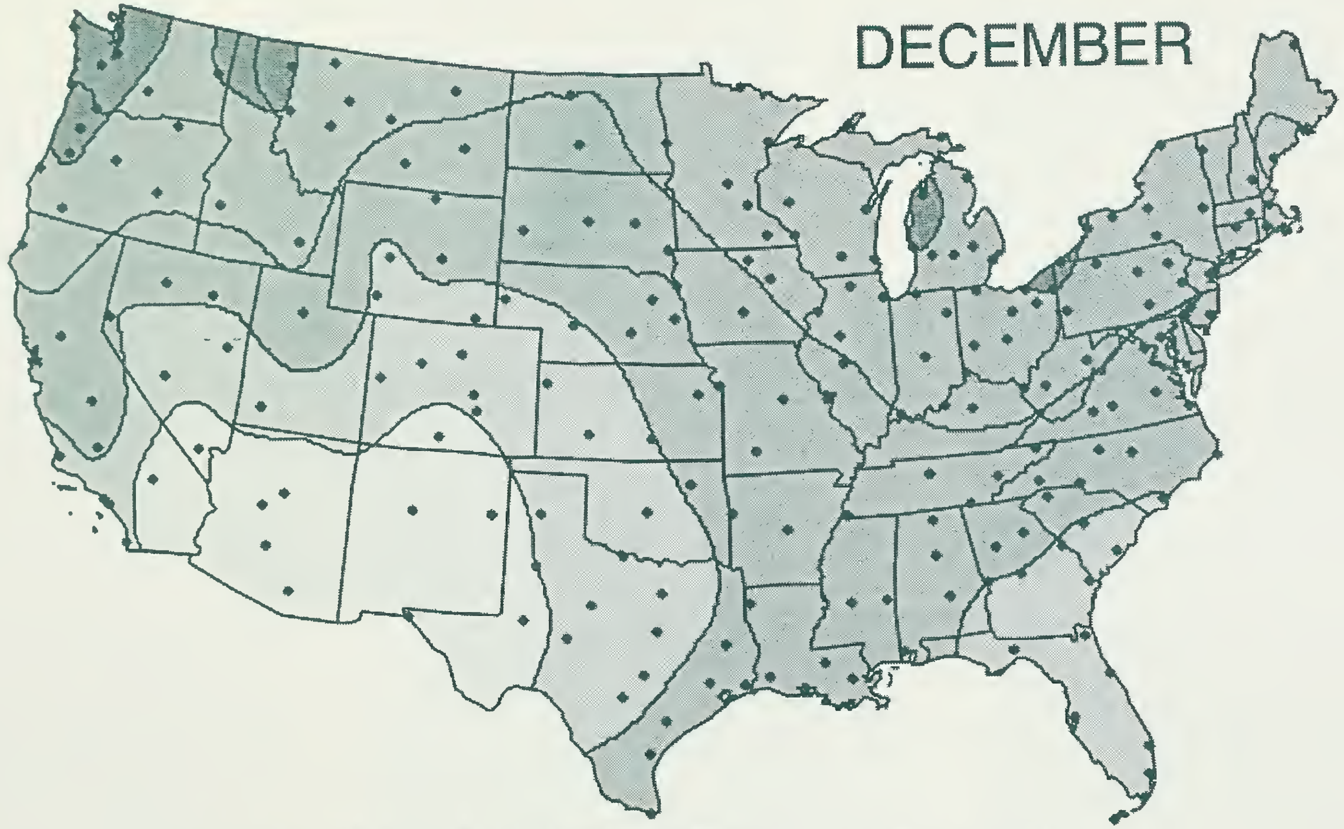
AMPS	Wattage	14ga	12ga	10ga	8ga	6ga	4ga	2ga	1/0	2/0	3/0
		Distance in Feet									
1	120	450	700	-	-	-	-	-	-	-	-
2	240	225	350	575	900	-	-	-	-	-	-
4	480	100	175	275	450	725	-	-	-	-	-
6	720	75	120	175	275	450	725	-	-	-	-
8	960	55	85	145	225	355	570	-	-	-	-
10	1200	45	70	120	190	300	480	765	960	-	-
15	1800	30	45	70	120	190	300	480	765	960	-
20	2400	-	35	55	90	145	225	360	575	725	915
25	3000	-	-	45	70	115	180	290	460	580	730
30	3600	-	-	-	60	95	150	240	385	485	610
40	4800	-	-	-	45	70	115	180	290	360	455
50	6000	-	-	-	-	55	90	145	230	290	365

Appendix B—Average Daily Solar Radiation

From: *Atlas for the Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, National Renewable Energy Laboratory (http://rredc.nrel.gov/solar/old_data/nsrdb/atlas/redbook)

Average Daily Solar Radiation Per Month

DECEMBER



Flat Plate Tilted South at Latitude + 15 Degrees

This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 239 sites of the NSRDB.

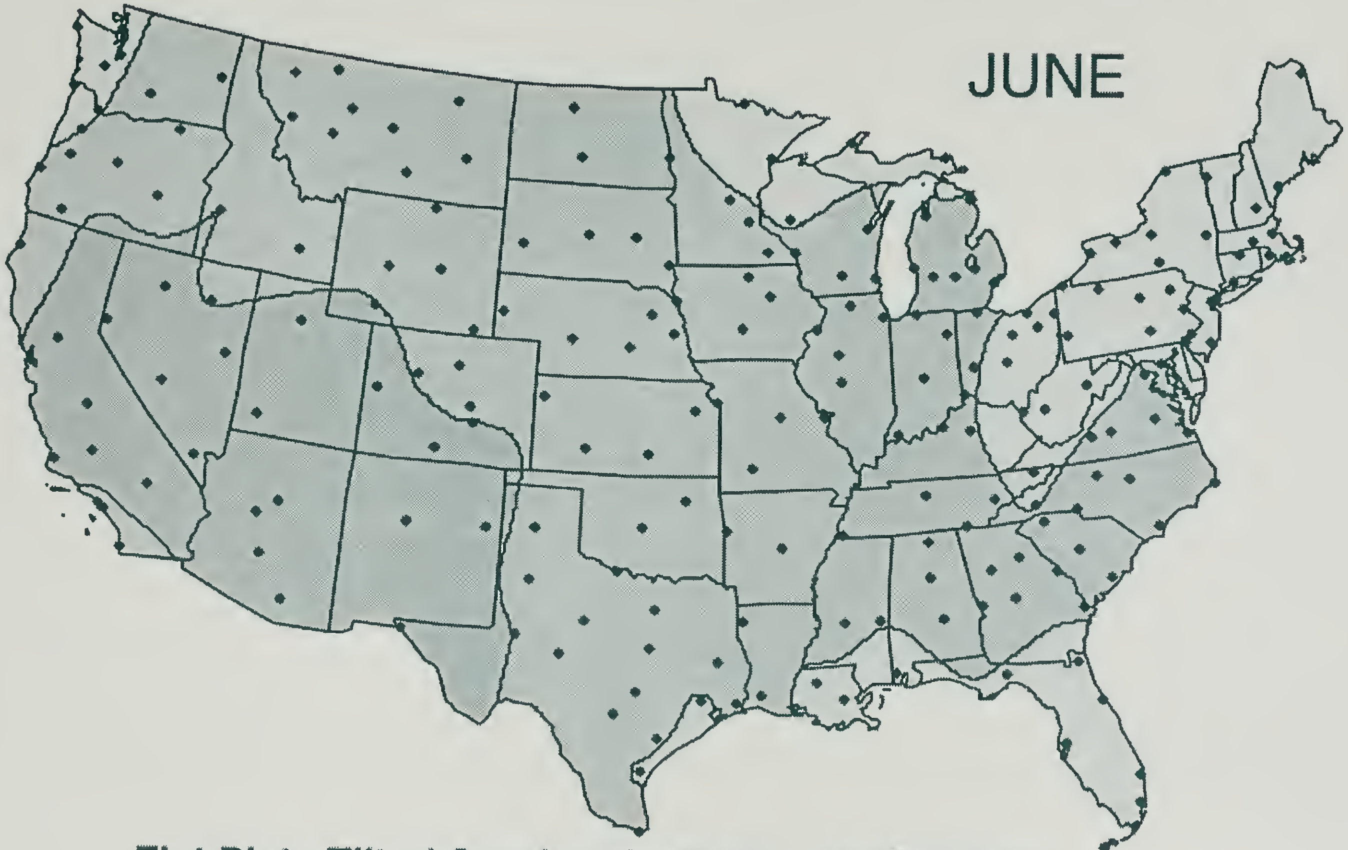
Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composites of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

Average Daily Solar Radiation Per Month

JUNE



Flat Plate Tilted South at Latitude - 15 Degrees

This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 239 sites of the NSRDB.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composites of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

Appendix C—Maintenance Checklist

From: *Maintenance and Operation of Stand-Alone Photovoltaic Systems.* 1991. Sandia National Laboratories: 187-188.

Maintenance Check List

Site/Location: ______________________________ Date: ____________

System Meters and Readouts

Battery Voltage: ______ Array Current: ______ Load Current:______

Charging LED: ☐ On ☐ Off LVD LED: ☐ On ☐ Off

Other LED: ______________ ☐ On ☐ Off

Other LED: ______________ ☐ On ☐ Off

Portable Metering

Array Voltage (test points D+ and D-)

Battery Voltage (test points L+ and L-)

System Current (test point M, P, or S)

- ☐ Circuit breakers not tripped, fuses not blown

Charge Controller

- ☐ Normal operation
- ☐ Wiring connections secure
- ☐ Temperature compensation probe secure and properly located
- ☐ Charge controller properly located and clean

System Wiring

- ☐ Grounding system continuous
- ☐ Disconnect switches operate properly
- ☐ All wiring connections and conduit secure, clean, and uncorroded

Batteries

- ☐ Battery tops clean
- ☐ All cells filled to proper levels
- ☐ Terminal connections secure, clean, protected from corrosion
- ☐ Tie downs and enclosure secure
- ☐ Venting system operating properly
- ☐ Equalization charge performed, if needed
- ☐ Batteries' states of charge recorded on copy of Inspection Record Sheet

Arrays

- ☐ Covers, frames, and reflectors clean and undamaged
- ☐ Seasonal tilt adjustment made, if applicable
- ☐ Tracking checked, if applicable
- ☐ All wiring connections and conduit secure, clean, and uncorroded
- ☐ Open circuit voltage and short circuit current of array and modules measured and recorded on copy of Inspection Record Sheet

Loads

- ☐ All loads operating properly
- ☐ Necessary maintenance and repair operations performed on loads

Inverters

- ☐ Normal operation
- ☐ Wiring connections secure and uncorroded

Current draw in idling mode (test point P):

____

Current draw in operating mode (test point P): ______________________________

Current draw of load (test point Q): ______________________________

Voltage to load (test points R+ and R-): ______________________________

- ☐ Inverter properly located and clean

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Robi Robichaud began studying renewable energy after teaching for 13 years in public and private schools. He received a bachelor's degree in accounting from the University of Massachusetts in Amherst during 1980. During the 1996-1997 academic year he attended the University of Massachusetts in Lowell, taking classes related to renewable energy. In 1998 he transferred to the University of Colorado to work on a master's degree in Building Systems. He has worked on renewable energy assessments and the design of solar photovoltaic systems.

Steve Oravetz graduated from the University of Washington in Civil Engineering and is a licensed Professional Civil Engineer. He began his career on the Wenatchee National Forest in 1980. He became Chief Engineer for the Northeastern Research Station in 1993. In 1996, he became Engineering Program Leader at MTDC.

Library Card

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Describes techniques used by the USDA Forest Service and other land management agencies when maintaining photovoltaic systems. Most of the examples are from the Western United States.

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